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MELLON INSTITUTE

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on

BALLISTIC PROTECTIVE BUOYANT MATERIALS

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TABLE OF CONTENTS

SUMMARY

Unbonded staple-fiber batts have been observed as impeding projectile penetration by causing it to tumble as well as increasing its effective size by wadding.

Batts prepared from steel staple fibers were found to be ineffective as ballistic armor.

The use of high-tensile wire screen in conjunction with an Orlon staple fiber batt increases the protective ability of the batt only when it is placed behind the fibers.

The ballistic test method has been modified by replacing the aluminum witness plate with a device capable of accurately determining the velocities of the projectiles which completely penetrate the armor samples. Using this technique, data have been obtained and plotted for samples of 1.0 dpf Orlon staple fiber batts, 1.5 dpf Dacron staple fiber batts and Doron body armor.

It appears that this modified ballistic test method is easier and more accurate than that originally proposed in determining the limiting velocity as well as the over-all protective efficiency of body armor. The dependence upon visual observation of the aluminum witness plate to determine the extent of the projectile's penetration of samples is eliminated. Also the tedious procedure of predetermining the initial striking velocities of the projectiles can be replaced by one which only requires a wide distribution of the initial velocities sufficient to plot a representative curve.

I. BALLISTIC EVALUATIONS

A. Observations Related to the Passage of the Projectile through Unbonded Staple-Fiber Batts

Visual examinations of the fibrous-liner test samples and the aluminum witness plates which are an integral part of the ballistic test equipment, have disclosed significant information concerning the passage of shrapnel-simulating projectiles through the samples.

It is logical to assume that if the spinning projectile were caused to tumble during its penetration of the fibrous liner, a greater expenditure of energy would be needed by the projectile for its passage. Tumbling of the simulators does occur in most of the staple-fiber samples at velocities lower than, equal to, and slightly greater than the protective or limiting velocities of the test samples. In those cases where the pellets are retained in the samples, they are found in various rest positions indicative of having yawed. The witness plates after being struck by those projectiles which barely passed through the samples, were found to be either dented, cracked or punctured with irregularly-shaped gaping holes. Only tumbling pellets or those askew could have caused these peculiar dents, cracks and holes. At extremely high velocities, the pellets completely penetrate both the samples and witness plates leaving circular holes whose diameters are only slightly greater than the diameters of the pellets. Obviously no tumbling occurs.

It has been observed that in every instance where the projectile has been caught and held, only the first several layers of webs in the carded batt sample have been in intimate contact with that projectile. The fibers in these layers are wrapped around the pellet, effectively increasing its size, and consequently causing it to expend more energy in pushing through the remaining multilayers of fibers. To obtain a more effective fibrous wad around the pellet, it may only be necessary to alter the characteristics of those several fiber layers at the front of the batt. This could possibly be accomplished by using shorter fibers, heat-sensitive fibers or by surface-treatment to increase the friction between the fibers and the projectile.

B. Steel Staple Fibers

Steel fibers (1" cut) prepared by the G. H. Tennant Co. were processed into a batt on a Rando-webber. The ballistic effectiveness of this batt was determined using samples that were 0.5" thick at an areal density of 20 oz./yd.^{2}. It was found that even at the low velocity of 552 ft./sec. a projectile completely penetrated the steel fibrous sample. Determinations at still lower velocities were not possible because of the difficulties encountered in weighing out the small amount of powder necessary. The poor protection against the projectile's penetration offered by the steel fibers may be attributed to any or all of the following reasons: (1) the extremely high friction between the steel fibers caused the sample to behave as a bonded batt enabling the projectile to cleave through, (2) due to the density of the steel, there are far less fibers in number when compared to an organic fiber sample of equal areal density, (3) the diameters of the steel fibers were extremely large when compared to the Orlon and Dacron staple fibers which we have found to be very effective.

C. Composite Structure - Orlon Fibrous Batt and High-Tensile Wire Screen

A composite structure was prepared using as the main body a 42 oz./yd.^{2} batt of hydrophobed 1.0 dpf Orlon fibers (3.0" cut) and a single layer of a high-tensile wire screen. The woven wire screen has a tensile strength of 250,000 psi and an areal density of 16 oz./yd.^{2} with the individual wire being 0.007" thick. The areal density of this screen is only slightly larger than that of a single layer of the nylon cloth body armor. The limiting velocity of this composite structure was found with the screen in front of the Orlon batts and also with the screen behind the batts. The limiting velocity when the screen was hit first by the projectile, was between 1129 ft./sec. and 1150 ft./sec.; while the limiting velocity of the sample with the screen placed in the back was between 1217 ft./sec. and 1269 ft./sec. This again proves that the position of any ballistic material in conjunction with the staple fiber batts is of great importance. With the screen in front of the sample, the projectiles produced circular holes in it, each hole being slightly larger in diameter than a projectile. However, with the screen behind the sample, an extremely large hole in comparison with the size of the projectile was noted, the hole being approximately elliptical in shape. This high tensile screen offered practically no resistance to the projectile's travel when the screen was in the front position; on the other hand it was more successful in containing the projectile and its accompanying fiber wad when the screen was placed at the rear.

D. Increasing the Scope of the Ballistic Test Method

As outlined in the Quarterly Report No. 2 for the research period from February 1, 1960 through April 30, 1960, the ballistic test method exployed in this laboratory is essentially the same as the proposed military standard ballistic acceptance test method for armor personnel employing a caliber .22T37(17 grain) fragment simulating projectile-prepared by the U. S. Marine Corp for the Department of Defense, Project No. 8415-0065. This method is capable of determining the protective quality or limiting velocity of personnel body armor, but, unfortunately only enables one to obtain the velocity of the test projectile before striking the sample. At high velocities where the sample is penetrated completely by the projectile, there is no indication of either the velocity of the projectile when it leaves the sample, or the amount of energy (loss of velocity) absorbed by the test specimen. We in this laboratory feel that a complete knowledge of the effectiveness of a ballistic armor should be known; not only its ability to stop projectiles, but also its efficiency in slowing down any projectile whose velocity is high enough to cause it to penetrate the armor. For this reason the present test method has been altered in order to obtain this latter information. The present test method makes use of an aluminum witness plate which is placed 6" behind the test sample. In the present new method the witness plate is eliminated, being replaced by two triggering devices which when connected to a chronograph (Berkeley/Beckman time interval meter) will be able to determine the velocity of the projectile leaving the sample. The first triggering device is positioned 6" behind the sample. The second is located at a distance of 1 ft. behind it. The distance between the triggering cards was measured accurately so that the actual velocity in ft./sec. could be determined precisely. This short distance of separation also serves the purpose of assuring that every projectile (after leaving the sample) would strike both triggering devices in case any projectile deviated slightly from its original path. The triggering devices are larger versions of the original wired-cards which have been normally used to detect velocity of the projectiles before striking the sample (see Quarterly Progress Report No. 2).

1. Hydrophobed 1.0 dpf Orlon Batt, 42 oz./yd.^{2}

The revised ballistic test was first used on a 0.5" batt composed of carded 1.0 dpf Orlon staple (3.0" cut) having an areal density of 42 oz./yd.^{2}. The fibers were coated with the Decetex-104 water-repellent. The data accumulated are presented in Table I with the representative curve being shown in Figure I. The table lists the velocities of the projectiles before striking and after leaving the samples, and also the reduction of the initial velocities due to the samples. The velocity loss is reported in both ft./sec. and percentage.

By referring to Figure I, one may more readily visualize the effectiveness of the sample in resisting the penetration of the projectile.

The percentage loss of initial velocity due to the sample (this may also be termed the percentage protection) is plotted against the initial velocity of the projectile before striking the target. Naturally, if all of the energy of the projectile is absorbed by the sample (i.e.: the initial velocity of the projectile is reduced by 100% due to the sample), then the limiting velocity or protecting velocity of the sample has been reached. If the curve in Figure I is extrapolated to 100% velocity loss, the limiting velocity is readily determined.

2. Hydrophobed 1.0 dpf Orlon Batt, 10 oz./yd.^{2}

Using the hydrophobed 1.0 dpf Orlon staple fibers identical to those in the previous ballistic test, batts were prepared at thicknesses of 0.5" and areal densities of 10 oz./yd.^{2}. The results obtained by the modified ballistic method are shown in Table II and Figure II. Since the limiting velocity of these samples is low (approximately 600 ft./sec. as determined from the curve presented in the Quarterly Report No. 2), the requirement of small quantities of the propellant powder was difficult to achieve. Therefore, the test was conducted at initial velocities above 800 ft./sec. Of course the results gave valuable information concerning the ballistic effectiveness at velocities above the limiting velocity. At an initial velocity of 800 ft./sec., the 10 oz./yd.^{2} Orlon batt was capable of reducing it by 30%.

3. Hydrophobed 1.5 dpf Dacron Batt, 42 oz./yd.^{2}

Using the Decetex-104 hydrophobed 1.5 dpf Dacron staple fibers (3.0 inches), a 0.5 inch batt was prepared at an areal density of 42 oz./yd.^{2}. This was subjected to the modified ballistic test method and the results tabulated in Table III as well as graphically presented in Fig. III. A comparison of the data for the one denier Orlon and the 1.5 denier Dacron as illustrated in Tables I and III shows that the Orlon has a higher limiting velocity. It is significant to note, however, that for projectiles velocities above 1200 ft./sec., both materials are approximately equal in their ability to slow down the passage of the projectiles.

4. Doron Body Armor, 175 oz./yd.^{2}

To determine the actual effectiveness of our fibrous batt liners as ballistic material, it is essential that they be compared with conventional body armor. To this end, plates of 1/8" Doron body armor were obtained and tested by the modified ballistic method. It is to be remembered however, that the Doron body armor has an areal density of 175 oz./yd.^{2}, a little more than 4 times the density of the fibrous liners. The velocity of the projectiles hurled at the Doron armor ranged from 1141 ft./sec. to 1613 ft./sec. As seen in

Table IV and Fig. IV, considerable variation exists in the ability of these armor plates to withstand the passage of the projectile through them. Unlike the protective action of the fibrous batts, the Doron appears to rely considerably upon the delamination of the individual layers of glass and resin. The inconsistencies of the results are undoubtedly due to a large extent to the irregularities encountered in the manufacture of such laminates. In spite of the variations in the results, however, it can plainly be seen that as the projectile velocity increased, the absorption of energy by the samples decreased. Although the Doron is definitely superior in impeding the passage of the projectile at striking velocities greater than the limiting velocity, the 42 oz./yd.^{2} Orlon batt compares very favorably as a protective garment at striking velocities of 1100-1200 ft./sec.

An interesting and significant interpretation of the ballistic data obtained for the Doron armor (175 oz./yd.^{2}) and the 1.0 denier Orlon batt (42 oz./yd.^{2}) points to the preparation of a body armor capable of protecting the wearer from 17 grain projectiles traveling at velocities up to 1600 ft./sec. A composite structure of 1 layer of Doron (1/8") and 1 layer of hydrophobed 1.0 dpf Orlon (0.5" batt) could offer this protection only if these materials were positioned properly.

If the Orlon batt were placed as the outside layer which would be struck first by the projectile traveling 1600 ft./sec., it would be easily penetrated, and the residual projectile velocity would be greater than 1357 ft./sec. (see Table I). This value far exceeds the limiting velocity of the Doron. The result would be complete penetration of the composite. However, if the Doron were placed outside to encounter the projectile first, the initial velocity of 1600 ft./sec. would be lowered by 36-37% during its passage through the Doron resulting in a residual velocity slightly in excess of 1000 ft./sec. (see Table IV). This value is less than the limiting or protective velocity of the Orlon batt. As a result the projectile would be completely contained.

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TABLE I.

Ballistic Performance

1.0 dpf Orlon Staple Fibers (3.0" Cut)

0.5" Batt at 42 oz./yd.^{2}

Hydrophobed with 4% Decetex-104

Velocity of Projectile (ft./sec.)		Velocity Loss Due to Sample	
Before Entering Sample	After Leaving Sample	(ft./sec.)	%
1167	186	981	84.1
1199	580	619	51.6
1237	1062	175	14.1
1355	1193	162	12.0
1381	1228	153	11.1
1424	1275	149	10.5
1497	1357	140	9.4

TABLE II.

Ballistic Performance

1.0 dpf Orlon Staple Fibers (3.0" Cut)

0.5" Batt at 10 oz./yd.^{2}

Hydrophobed with 4% Decetex-104

Velocity of Projectile (ft./sec.)		Velocity Loss Due to Sample	
Before Entering Sample	After Leaving Sample	(ft./sec.)	%
796	565	231	29.0
822	585	237	28.8
842	606	236	28.0
849	620	229	26.9
919	682	237	25.8
924	710	214	23.2
931	707	224	24.1
1046	872	174	16.6
1208	1039	169	14.0
1420	1335	85	6.0

TABLE III.

Ballistic Performance

1.5 dpf Dacron (3.0")

0.5" Batt at 42 oz./yd.^{2}

Hydrophobed with 4% Decetex-104

Velocity of Projectile (ft./sec.)		Velocity Loss Due to Sample	
Before Entering Sample	After Leaving Sample	(ft./sec.)	%
1094	8	1086	99.3
1136	185	951	83.7
1208	1020	188	15.6
1244	1044	200	16.1
1272	1119	153	12.0
1282	1113	169	13.2
1333	1174	159	11.9

TABLE IV.

Ballistic Performance

1/8" Doron Body Armor

175 oz./yd.^{2}

Projectile Velocity (ft./sec.)		Velocity Loss Due to Sample	
Before Entering Sample	After Leaving Sample	(ft./sec.)	%
1141	206	935	81.9
1147	510	637	55.5
1188	355	833	70.1
1199	532	667	55.6
1202	357	845	70.3
1219	590	629	51.6
1222	529	693	56.7
1225	551	674	55.0
1241	511	730	58.8
1246	537	709	56.9
1253	562	691	55.1
1262	483	779	61.7
1288	587	701	54.4
1299	624	675	52.0

TABLE IV.

(Continued)

Projectile Velocity (ft./sec.)		Velocity Loss Due to Sample	
Before Entering Sample	After Leaving Sample	(ft./sec.)	%
1392	681	711	51.1
1401	745	656	46.8
1408	800	608	43.2
1462	847	615	42.1
1534	956	578	37.7
1613	1019	594	36.8

Figure I

Hydrophobed 1.0 dpf Orlon (3.0")

0.5" Batt at 42 oz./yd.²

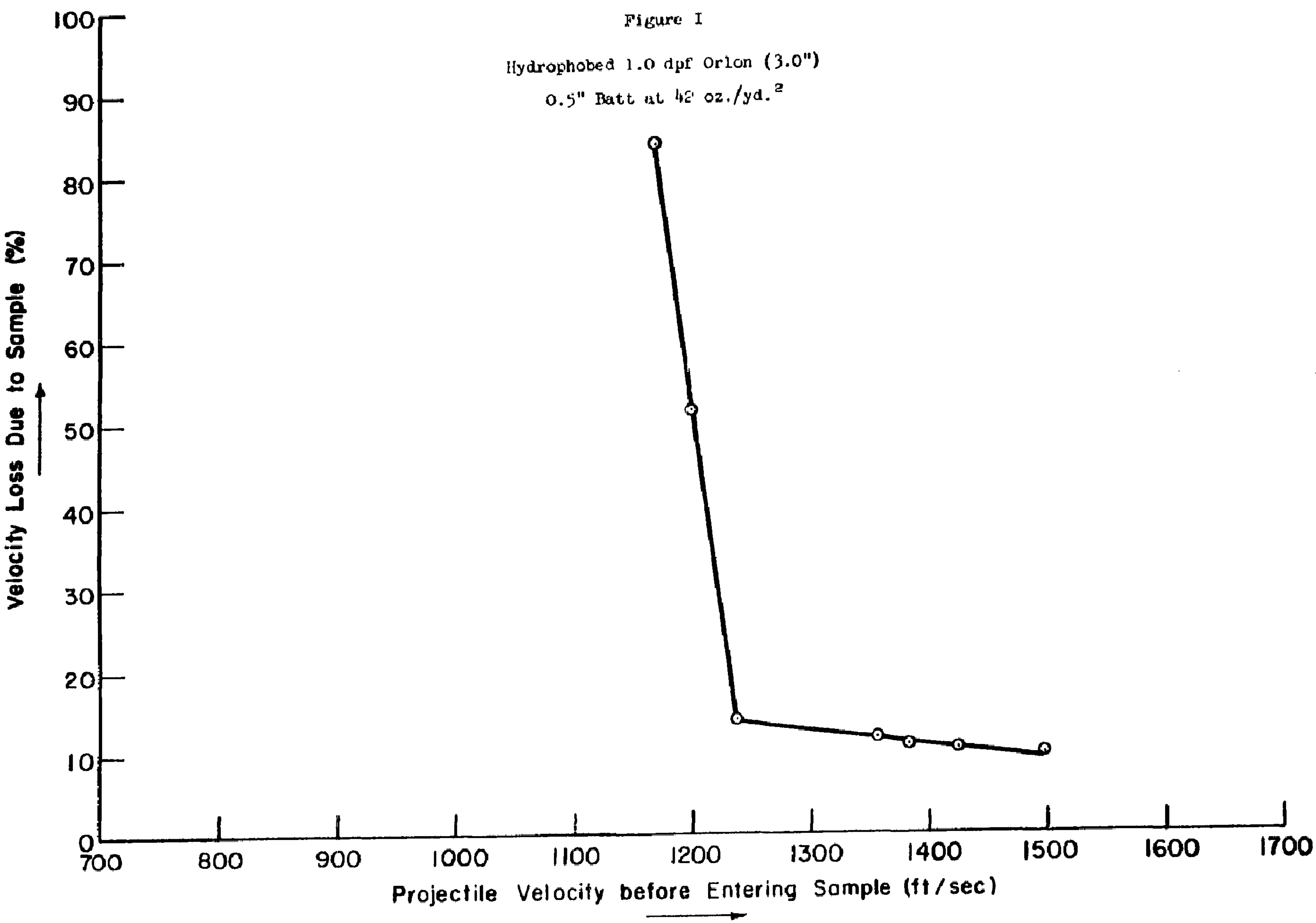


Figure 12

Hydrophobed 1.0 dpf Orlon (3.0")

0.[illegible]" Batt at 10 oz./yd.^{2}

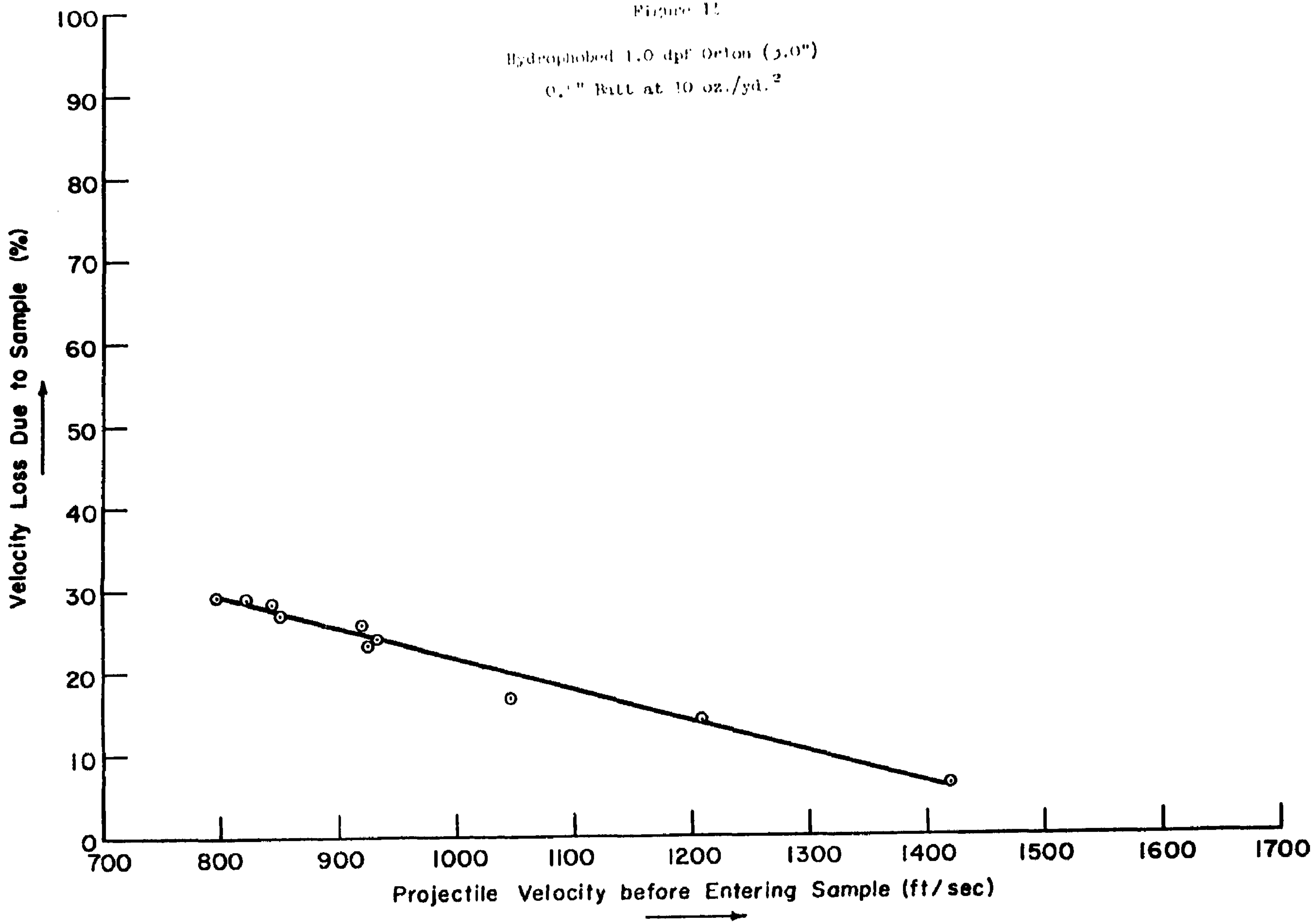


Figure III

Hydrophobed 1.5 dpf Dacron (3.0")

0.5" Batt at 42 oz./yd.^{2}

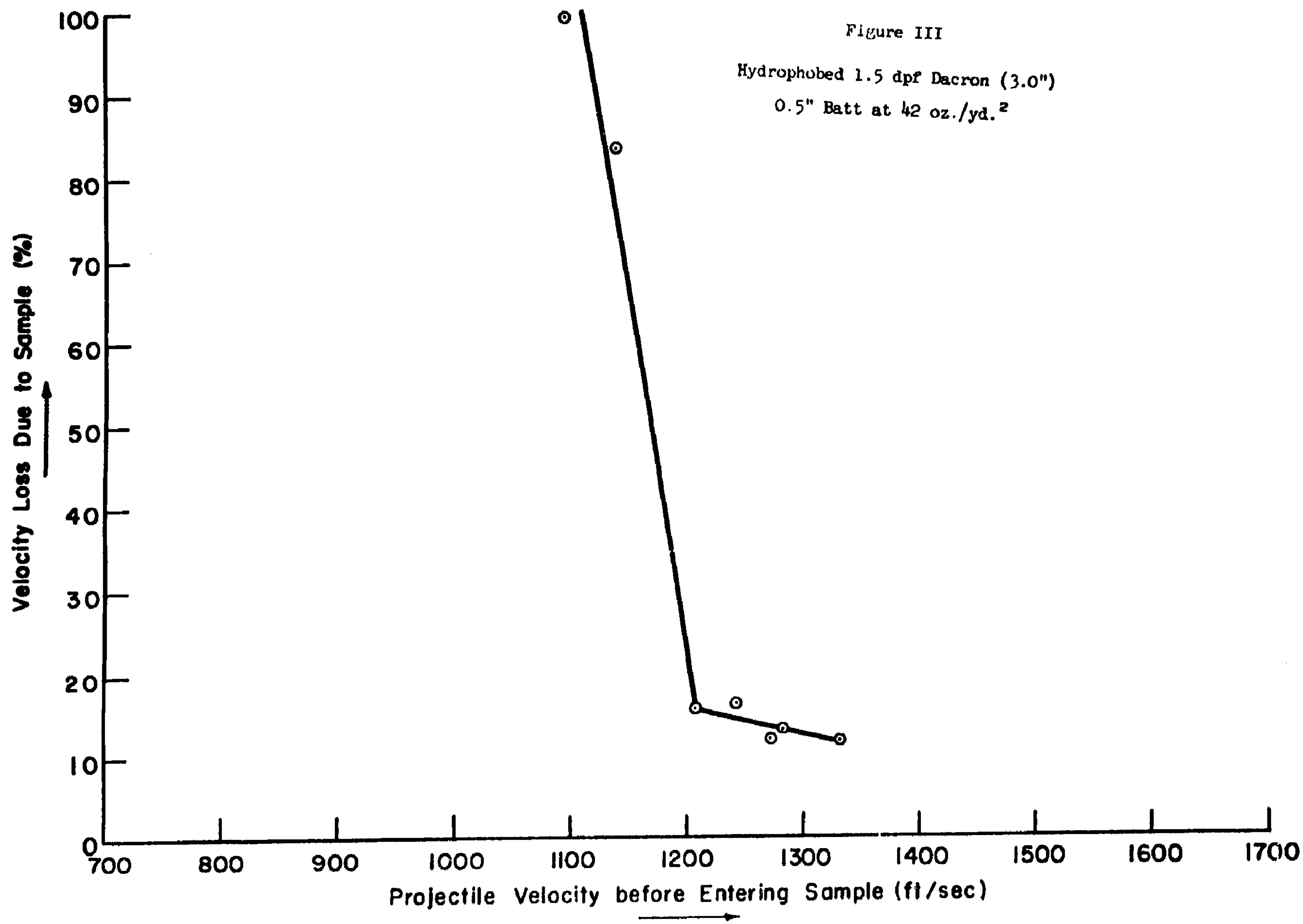
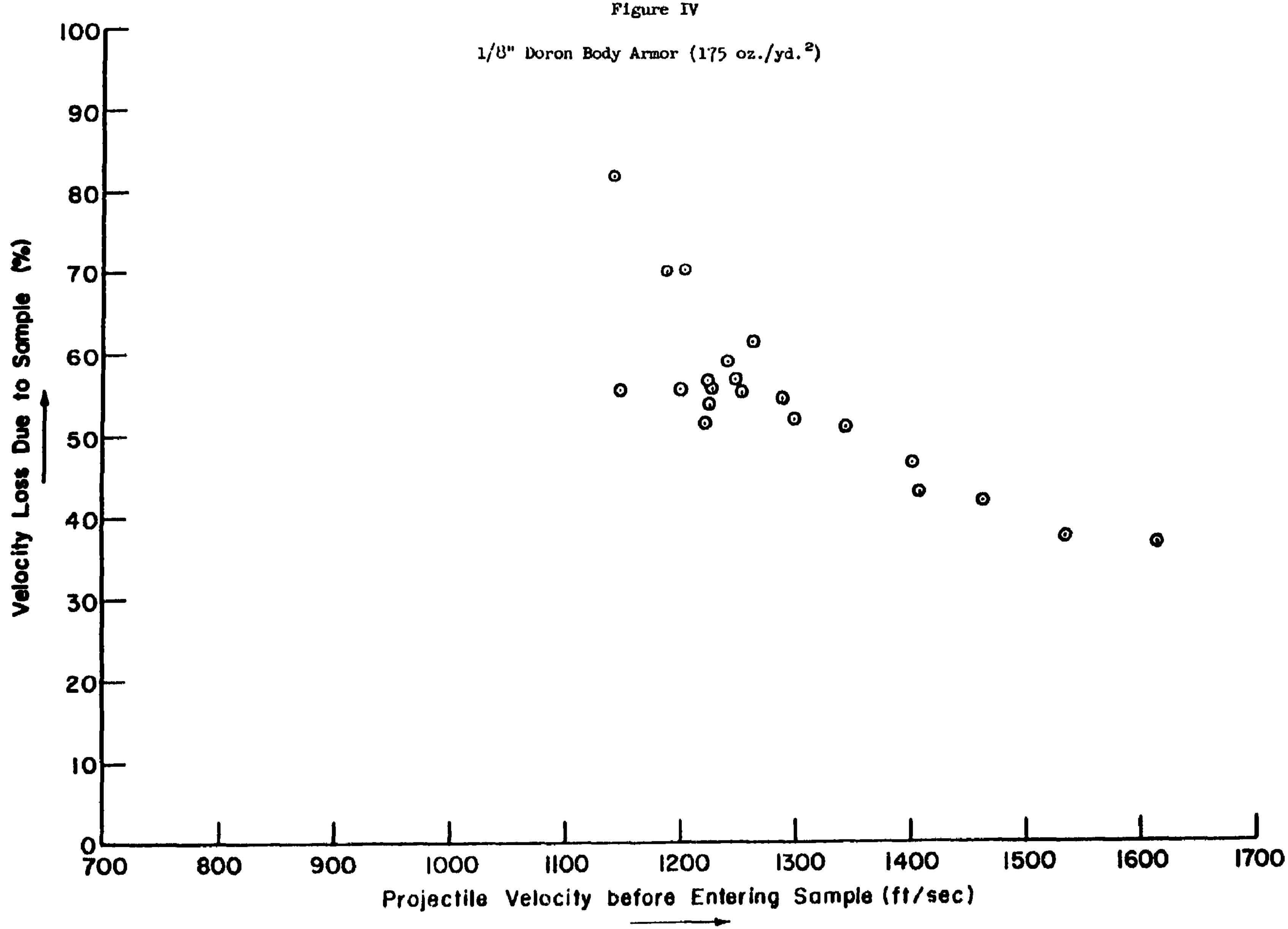


Figure IV

1/8" Doron Body Armor (175 oz./yd.^{2})



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